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DEVELOPMENT OF SPECIAL LUBRICANTS
FOR BALL BEARINGS OPERATING IN
VACUUM

CONTRACT NAS 5-9624

FINAL REPORT

PREPARED BY

NEW HAMPSHIRE BALL BEARINGS, INC.

PETERBOROUGH, NEW HAMPSHIRE

MAY, 1973

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

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SUMMARY

A ball bearing life test program was performed to obtain data on the efficiencies of various lubricated and self-lubricating ball retainer systems for instrument bearings in a vacuum environment. The program utilized light to moderate radial loads and relatively low speeds on a NASA-GSFC designed and supplied test rig. Several systems were found which gave acceptable bearing life under the test conditions used, but the most consistent low running torques after testing resulted from oil lubrication.

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DEVELOPMENT OF SPECIAL BEARINGS FOR BALL BEARINGS OPERATING IN VACUUM

INTRODUCTION

One of the more demanding applications for ball bearings and rotating components in general, is in high vacuum environments. Conventional oil or grease lubrication normally is not acceptable because of vaporization of the more volatile compounds in the lubricant, resulting in degradation of the bearing operating characteristics and/or fogging of optical surfaces within the same envelope. Solid film lubricants can and have been utilized, but the presence of these media usually raise starting and running torque values to unacceptable levels for most sophisticated applications.

The purpose of the present contract was to test the efficiency of various alternative lubricating systems, particularly self-lubricating compounds. The test equipment used in the program was designed and built by NASA-GSFC personnel(1) and was later modified by New Hampshire Ball Bearings, Inc. (NHBB).

Test Program

As originally funded, the NHBB tasks on this contract were limited to supplying bearings and performing failure analyses. However, under Modification 2, the test equipment and test responsibility were transferred to NHBB, the choice of retainer and lubricant materials remaining with the NASA-GSFC Technical Officer.

For comparison purposes, Phase I of the test program included air tests and vacuum tests under various loads, plus air tests on an NHBB standard radial load tester. The tester is described in Appendix I. All of these tests were performed on bearings utilizing retainers of Duroid, a proprietary PTFE/molybdenum disulfide/glass fiber composite material made by Rogers Corporation. Phase II was devoted to comparing various materials under identical operating conditions. Shortcomings of the test equipment noted in Phase I were corrected prior to embarking on Phase II.

Equipment Modification

During the Phase I test program, it was found that improvements in three aspects of the test equipment were desirable:

1. Test Weights

As illustrated by Figure 1, the test weights allowed for minimal distance between the preloaded pair of bearings. This resulted in a very high length/width ratio for the test weights. Post-test examination in a number of instances showed a distinct indication of individual weights wobbling during the test. Such a condition would place uneven loads on the bearing pair involved, with probably erratic test results.

2. Preloading

The original concept placed all weights and spacers on the common shaft, then locked up the whole assembly by torque on a single nut. Because of the number of interfaces involved,

plus five bearing pairs with individual preload spacers, the fixture buildup was very time-consuming. Also, in many instances, the preload would change during pretest check-out, necessitating a rebuild operation.

3. Test Termination Indication

As originally designed, the test weights, after attaining a 90° swing, hit a stop bar which supposedly prevented them from rotating any further. The design philosophy was that the test could be continued on the remaining bearing pairs, the torque in the failed bearings being insufficient to cause any perturbation in the continued testing. In actual practice during Phase I, one of the test weights on a failed bearing pair slipped by the stop bar and caused considerable damage to the test fixture.

The difficulties outlined in (1) and (2) were overcome by redesigning the test weights. Utilizing the original test weight frame, the space between the preloaded bearing pair was increased to improve the geometric stability shown in Figure 2. The spacer between the bearing pair was designed as a barrel/sleeve unit with a micrometer thread mating surface and micrometer markings on the sleeve O.D. The preload is set by rotating the sleeve relative to the barrel to increase the length of the unit. The rough preload is set by means of the micrometer markings, then checked by swings as in the original method (Ref 1). After proper preloading is achieved, the setting is locked in by means of a set screw in the sleeve (Figure 3).

This system permits individual preload setting of each bearing pair at the cost of reducing the number of bearing pairs which can be tested simultaneously from five to three. Figure 4 shows a module with one of the revised discs installed.

An electronics shutdown circuit was designed and built to eliminate dependence on the stop bar for restraining failed bearings. This unit cuts off power to the test module motor when the 90° reed switch is tripped. If it is desired to continue testing on the remaining bearing pairs, it is necessary to remove the failed bearings from the module. While this is inconvenient it is considered preferable to the possibility of damaging the test module.

Test Results and Discussion

Table I shows results obtained using the original test disc configuration, five discs per module. As indicated, the first 2 ounce air test was the only one in which bearing pairs were removed as they failed and the test restarted. All other tests are "first failure" results. In both the 2 ounce and 4-1/2 ounce tests, the Duroid retainers appear to run significantly better in vacuum than they do in air. The difference was approximately one order of magnitude at both of these test weights. The 9 ounce tests are considered to be inconclusive because of extreme difficulties encountered in getting these modules to run at all. The vacuum test which ran for 82.2 hours, for instance, required four rebuild and restart sequences before attaining the listed life, the aborted starts ranging in duration from 2 to 5 minutes before 90° swing occurred.

Test results on several retainer systems run in the modified (3 disc) configuration at 3600 rpm under a 2 ounce load are given in Table II .

Phenolic retainers lubricated with sputtered MoS_2 showed high torque characteristics early in the test, one disc making intermittent contact with the 30° switch during the first 100 hours. Torque then became smoother and no further difficulties were noted. A slight amount of retainer wear debris was found under one disc after completion of the test. MIL-STD-206 torque tests were performed on these bearings before and after test and the races are shown in Appendix IIA. Both average running torque (ART) and maximum running torque (MRT) ranged from zero change to approximately a 500% increase. All traces were random with no appearance of cyclic spikes which could be attributed to brinelling, etc.

Bearings containing leaded commercial bronze (CDA Alloy 316) retainers lubricated with Krytox 143 AC oil showed higher than normal torque throughout about the first half of the test duration, running at 15 to 25° with occasional 30° contact in the early part of the test. During the latter half of the test, the torque abated to a more normal level. However, two power shutdowns occurred during this period and, in each instance torque was high during the first few hours after restarting, although no vacuum loss was experienced. Appendix IIB shows MIL-STD-206 torque traces for these bearings. A pronounced retainer waver is visible in the torque traces of three of the six test bearings, indicating some retainer instability. In general, neither the ART nor MRT changed drastically after testing, although some pronounced dirt

spikes appeared in bearing #3 to increase the MRT significantly.

The only retainer material which failed during the test cycle was CDA Alloy 544 lubricated with sputtered MoS_2 . These bearings started more smoothly than the other types, showing abrupt 5° swings, but no large or erratic swings. At about 3800 hours one disc began contacting the 30° switch intermittantly. Less than 100 hours later a different disc hit the 90° switch. The unit was restarted and ran about 150 hours, showing intermittent 30° swings, before the 90° switch was again contacted. This disc would not return to 0° and the test was terminated. MIL-STD-206 torque traces for these bearings are shown in Appendix IIC. It is obvious from the traces that the disc containing bearings #1 and #2 caused the failure. The wide separation of the peaks after test suggest that the balls were ploughing through a considerable mass of debris rather than running over small irregularities. With the exception of this pair, the other bearings appear to have suffered no greater torque increase, and perhaps less, than those with phenolic/sputtered MoS_2 retainer. In this instance, at least, it appears possible that the sputtered coating, rather than the substrate, may have caused the failure.

Successful test runs also were made on unlubricated bearings containing retainers of Salox M, Duroid and a Boeing composite material.

The Ekonol retainers were not run because of extreme roughness in bearing running characteristics. Teardown of the unit revealed the trouble to be small debris particles, apparently from the retainer. The bearings were

cleaned and rebuilt, but the roughness recurred. When a second tear-down again showed particles in the bearings, the test was discontinued.

Table III lists the life obtained in air on bearings with Duroid retainers run for comparison on an NHBB 16-head radial load tester. Five pairs were started, but one was lost during a move of the test equipment during the nearly five years running. Post-test MIL-STD-206 torque traces were taken after the bearings were removed from test. At removal, there was so much wear dust from the retainer that torque testing was impossible. The torque traces shown were obtained by blowing the dust out of the bearings with compressed air prior to test. The traces (Appendix IID) indicate that, with the debris removed, ART is as low as normally would be expected if the bearings were new. Variations in MRT are attributed to incomplete debris removal rather than to any basic differences in the bearings.

Conclusions

Since bearing autopsies were not included in this contract, conclusions drawn relating to causes of bearing failures must be considered tentative.

1. Under low load conditions on bearings lubricated only by self-lubricating retainer materials, the most probable cause of bearing failure is increased torque resulting from a buildup of retainer wear debris.
2. Bearings utilizing Duroid retainers as the only source of lubricant apparently operate more efficiently in vacuum than in air.
3. Data obtained from this study are insufficient to permit firm

conclusions to be drawn on the efficiency of sputtered MoS₂ for vacuum applications. It is indicated, however, that wide variations in bearing life may result from the use of this lubricant, possibly from differences in adhesion, etc.

4. Based on post-test running torque measurements, the best overall results on lubricated bearings in this brief test series were obtained using an oil lubricant.
5. The equipment modifications and test generated by this contract provide the basis for expanded test programs to yield valid results on different retainer systems, higher loads, different speeds, oscillatory and stepping movement.

TABLE I

Results of Tests Run on NASA-GSFC High Vacuum Equipment at NHBB.
 Five Bearing Pairs per Test Module (Original Configuration)

SR2-6B15K68

Test Wt. (Oz.)	Test Medium	Life (Hours)	Remarks
2	air	312-4642	(1)
2	air	214.5	failed
2	vacuum	6042	failed
2	vacuum	3687	failed
4-1/4	air	180.5	failed
4-1/4	air	22.5	failed
4-1/4	vacuum	1877	failed
4-1/4	vacuum	1737	failed
9	air	104.5	failed
9	air	not run	(2)
9	vacuum	0.8	failed
9	vacuum	82.2	failed

(1) Pairs removed as they failed. First failure at 312 hours,
 last at 4624 hours.

(2) Eliminated because of difficulties encountered with this test
 configuration.

TABLE II

Test in High Vacuum of Various Retainer Materials - 2 oz. Test Weight,
3600 rpm. Three Bearing Pairs per Test Module (Modified Configuration).

SR2-6B15K68

Retainer Material	Lubricant	Life (Hours)	Remarks
Duroid	none	5000	Removed
Salox M	none	4800 ⁽¹⁾	Removed
Boeing	none	5000	Removed
Ekonol	none	would not run	
CDA Alloy 544	sputtered MoS ₂	3923	Failed
Phenolic	sputtered MoS ₂	5000	Removed
CDA Alloy 316	Krytox 143 AC oil	5000	Removed
CDA Alloy 316	none	81 ⁽²⁾	Failed

(1) Test terminated because of support bearing failure.

(2) This module was tested with unlubricated bearings by mistake, but
forms a basis for comparison for the Krytox 143 AC oil.

TABLE III

Long Term Air Tests on SFR2B15K68 Bearing Pairs on NHBB 16-head
Life Tester.

Test Load (gms)	Test Speed (rpm)	Life (hrs)	Remarks
23	3000	40364	Removed- no failure

TABLE IV

Identification of Retainer Materials Utilized in Test Bearings.

<u>Material</u>	<u>Manufacturer</u>	<u>Description</u>
Duroid	Rogers Corporation	PTFE/Molybdenum disulfide/ glass fiber composite
Salox M	Allegheny Plastics	Fluorocarbon/Bronze composite
Ekonol	Carborundum	Aromatic polyester
Phenolic	Synthane	Linen cloth reinforced
Boeing 4-53-3	Boeing	Molybdenum Disulfide/Mo/Ta/Ag Composite
CDA #316		1.3-2.5% Pb, 0.7-1.2% Ni, bal Cu
CDA #544		3.5-4.5% Pb, 3.5-4.5% Sn, 1.5-4.5% Zn, bal Cu

3. Closeup of Preload Mechanism Showing Micrometer Barrel
Markings and Lock Screw

4. Test Module With One Modified Disc Installed

Bibliography

1. Ward, B.W. and Wall, J.L., "Design and Development of a Radial Load Ball Bearing Test System and Some Preliminary Results", NASA-GSFC X-723-69-226, May, 1969.

Appendix I

New Hampshire Ball Bearings 16-head Radial Load Life Tester

The equipment is shown in Figure 5. It consists of 16 test spindles driven by belts from a common motor. Single bearings or pairs are locked into a peripheral ring which constitutes the radial load. This test assembly is then placed on a test spindle and held in place by a hex nut which also applies the preload where required. As torque increases during the test, the assembly begins to oscillate, eventually attaining sufficient drag to cause the entire assembly to rotate 360°. When this occurs, a switch is tripped which shuts off the tester and actuates a light on the console corresponding to the test station number. The failed bearings can then be removed and the test restarted.

Appendix II

MIL-STD-206 Torque Traces

for Test Bearings

- A. Phenolic retainers lubricated with sputtered MoS₂
- B. CDA Alloy #316 lubricated with Krytox 143 AC oil
- C. CDA Alloy #544 lubricated with sputtered MoS₂
- D. Duroid retainers run in air on NHBB 16-head life tester (post-test torque traces only)

A. Phenolic retainers lubricated with sputtered MoS₂

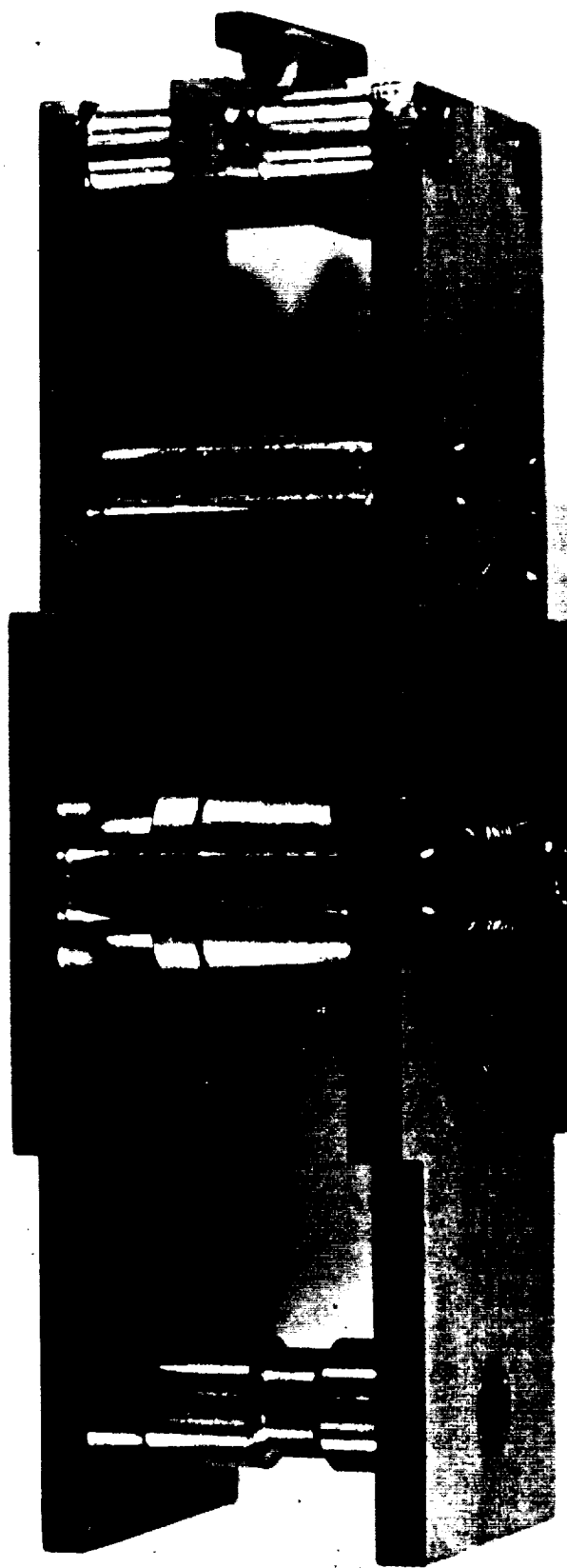
B. CDA Alloy #316 retainers lubricated with Krytox 143 AC oil

C. CDA Alloy #544 retainers lubricated with sputtered MoS₂

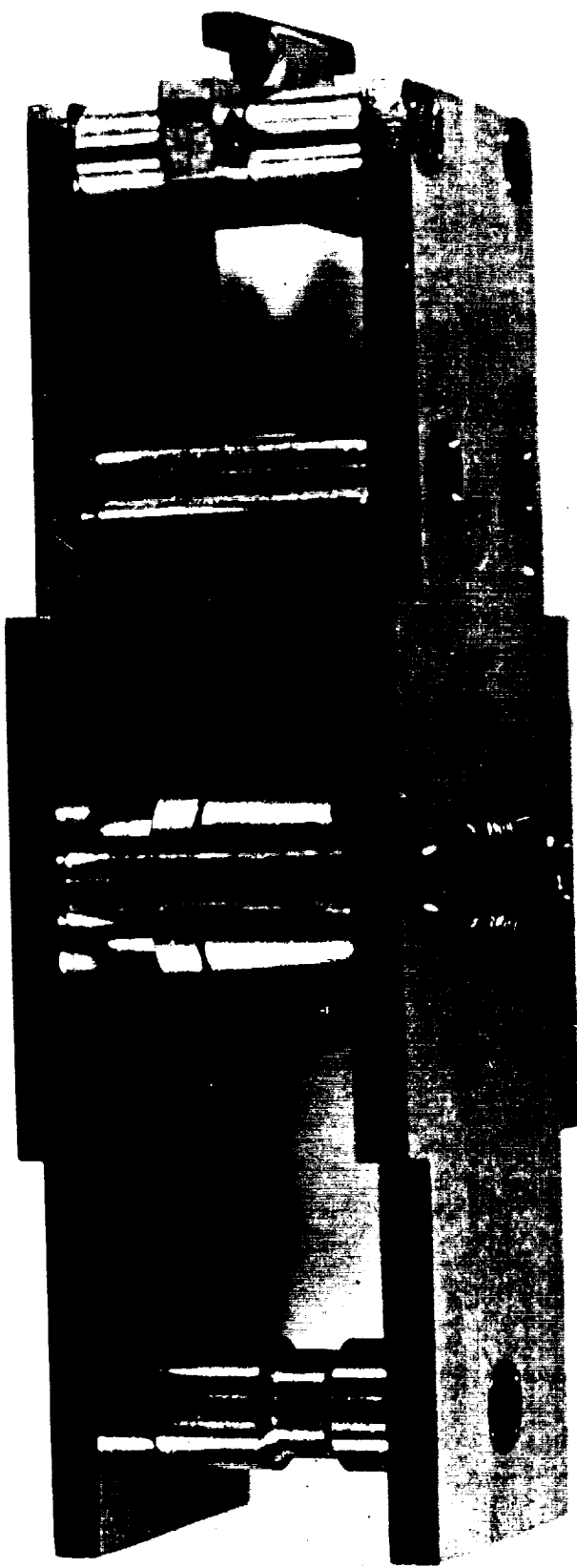
D. Duroid retainers run in air on NHBB 16-head life tester (post-test torque traces only)



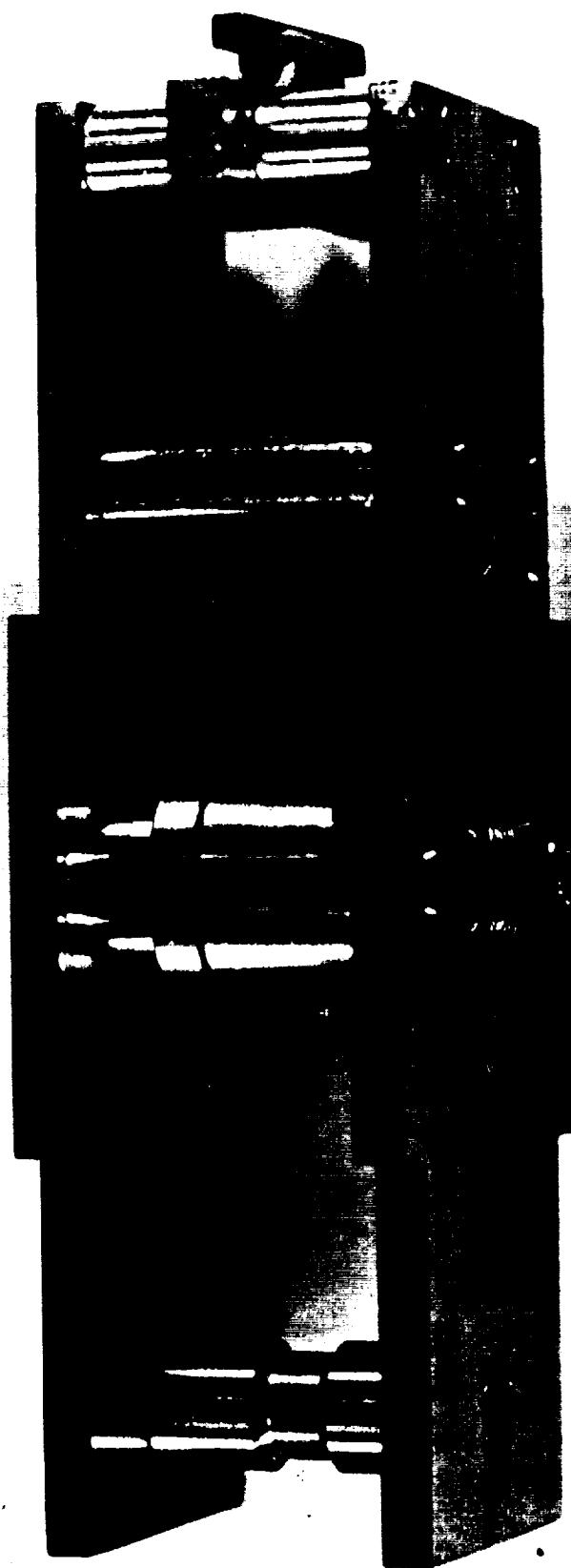
NAS 5-9624 FIG. 1



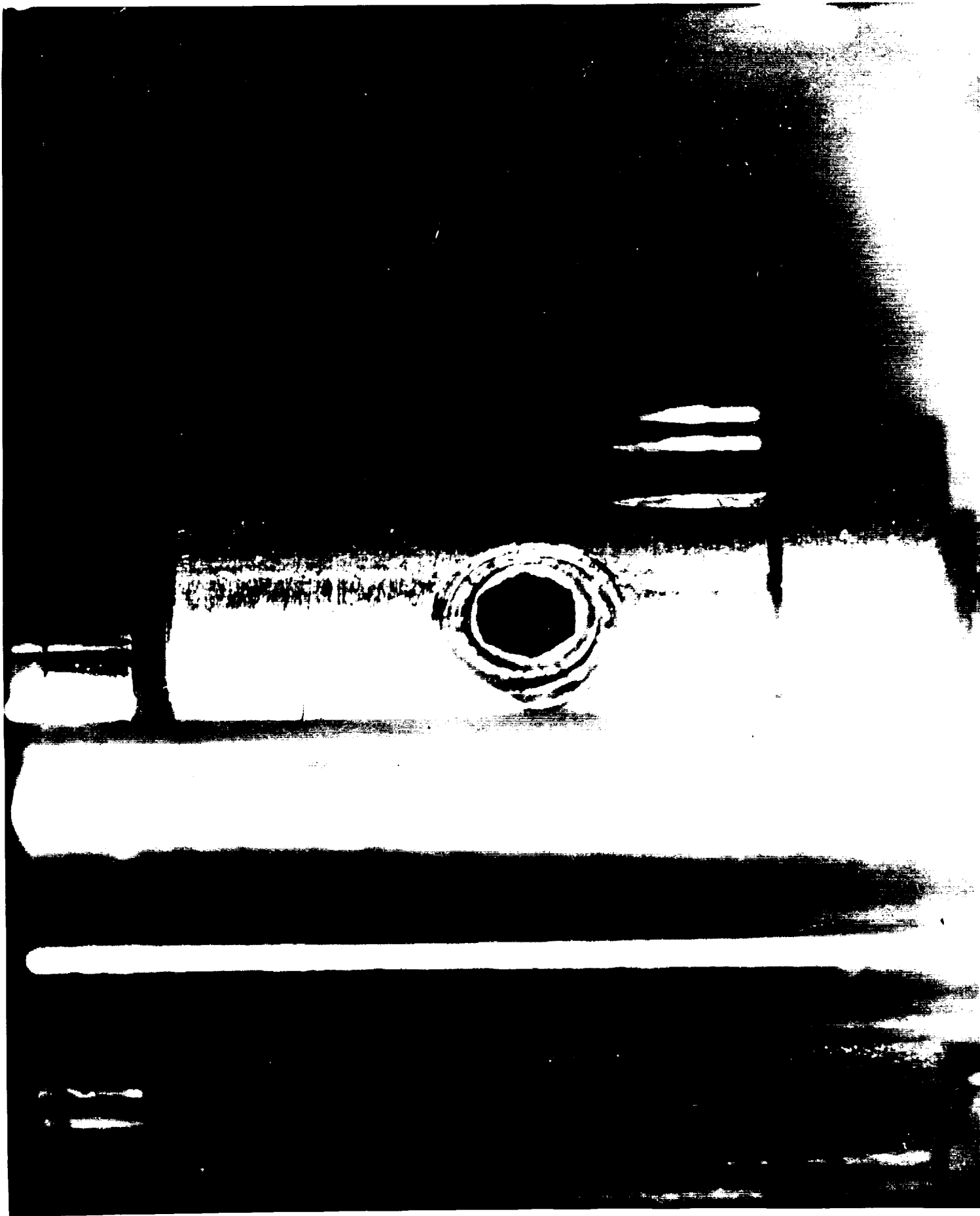
NAS 5-9624 FIG. 2



NAS 5-9624 FIG. 2



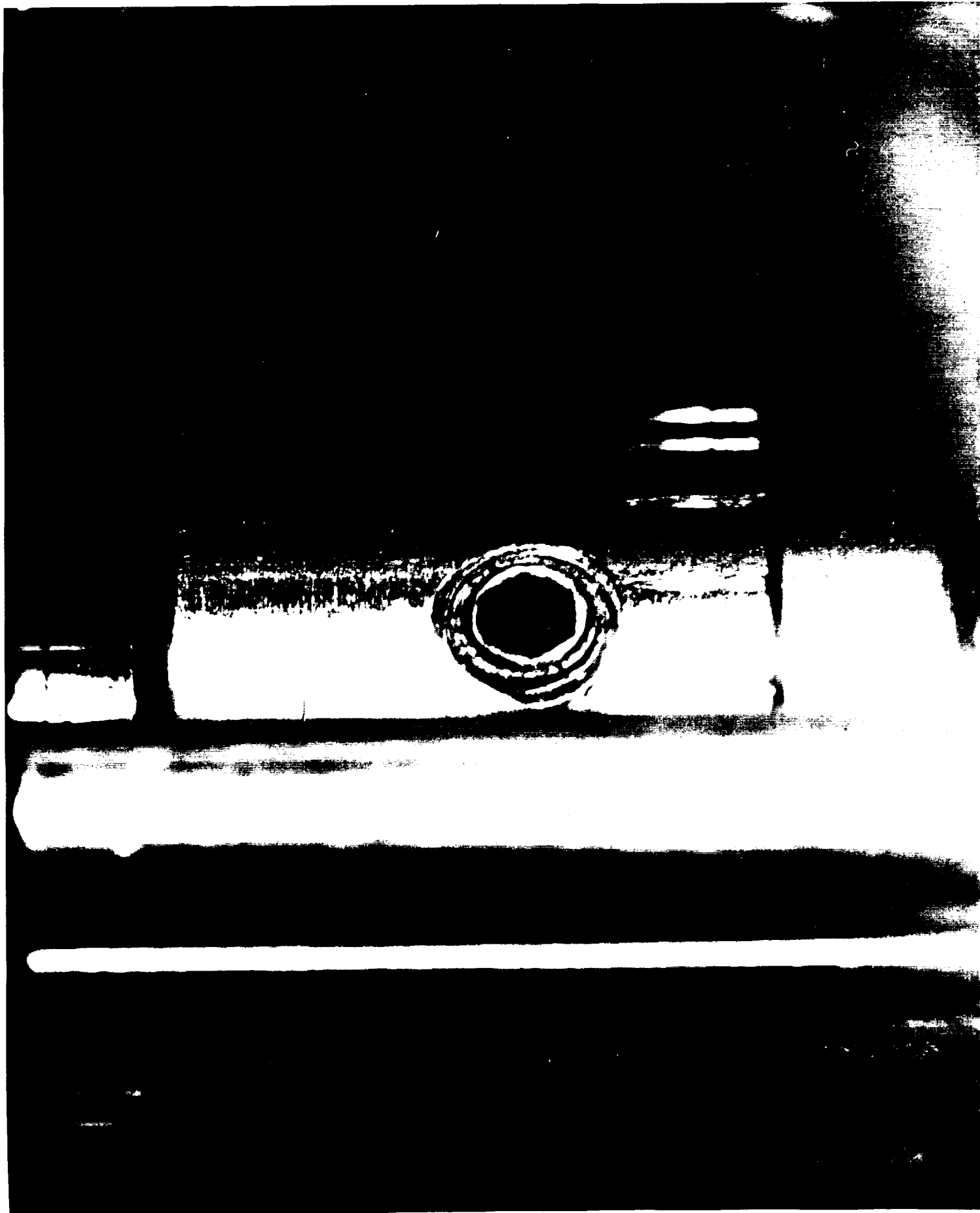
NAS 5-9624 P46.2



NAS 5-9634 F8.13

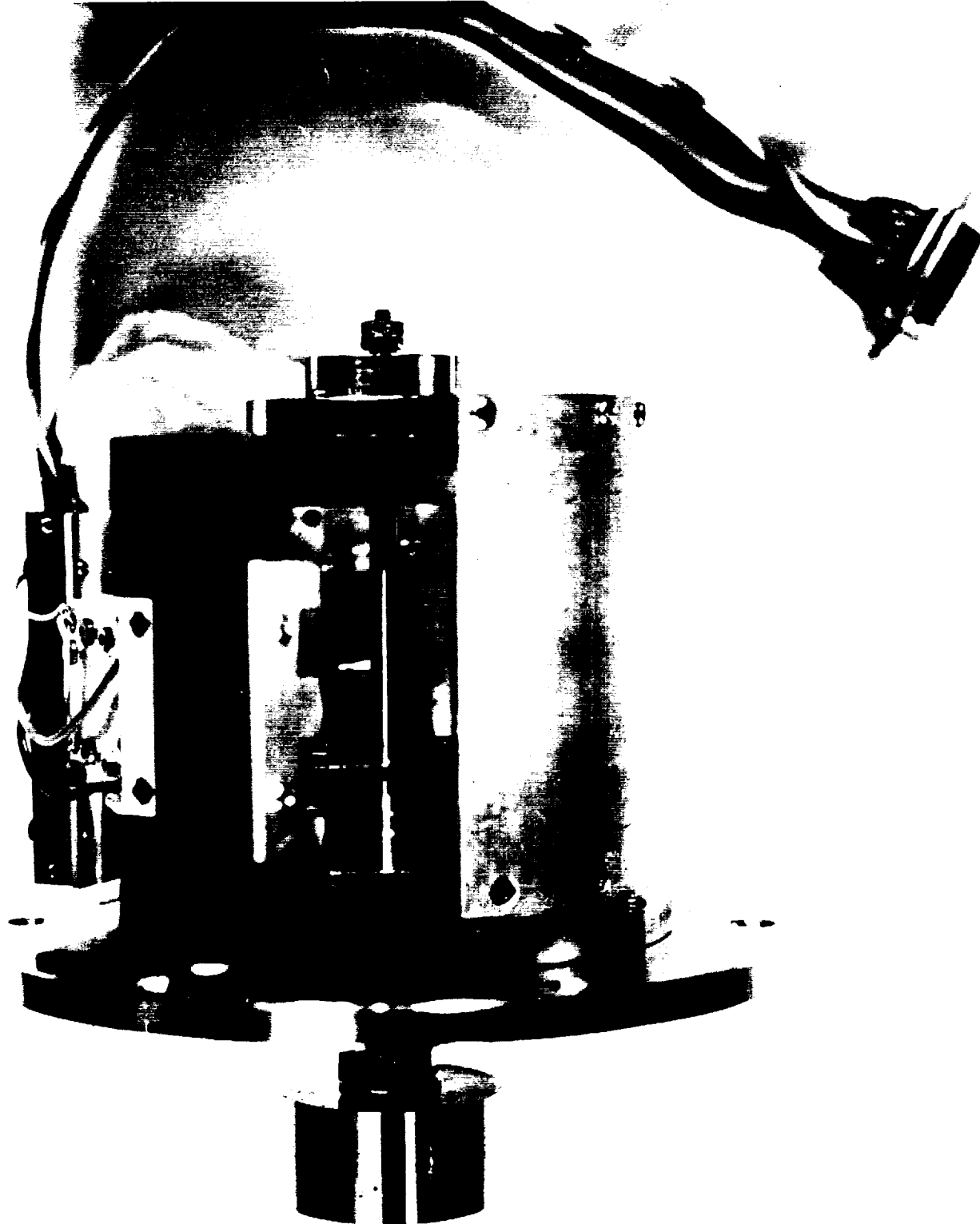


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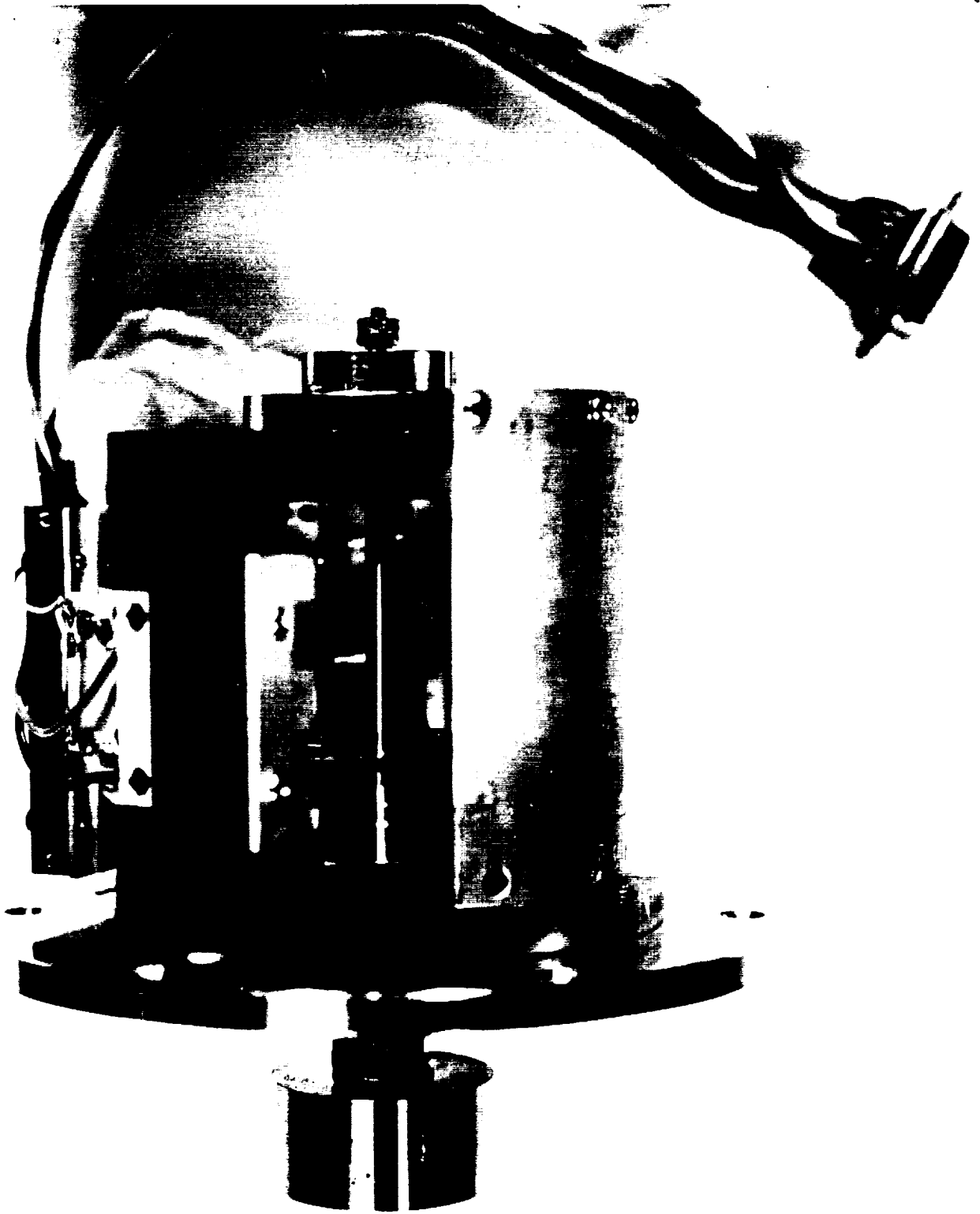
UASS-9624 FIG. 3

UASS-9624 FIG. 3

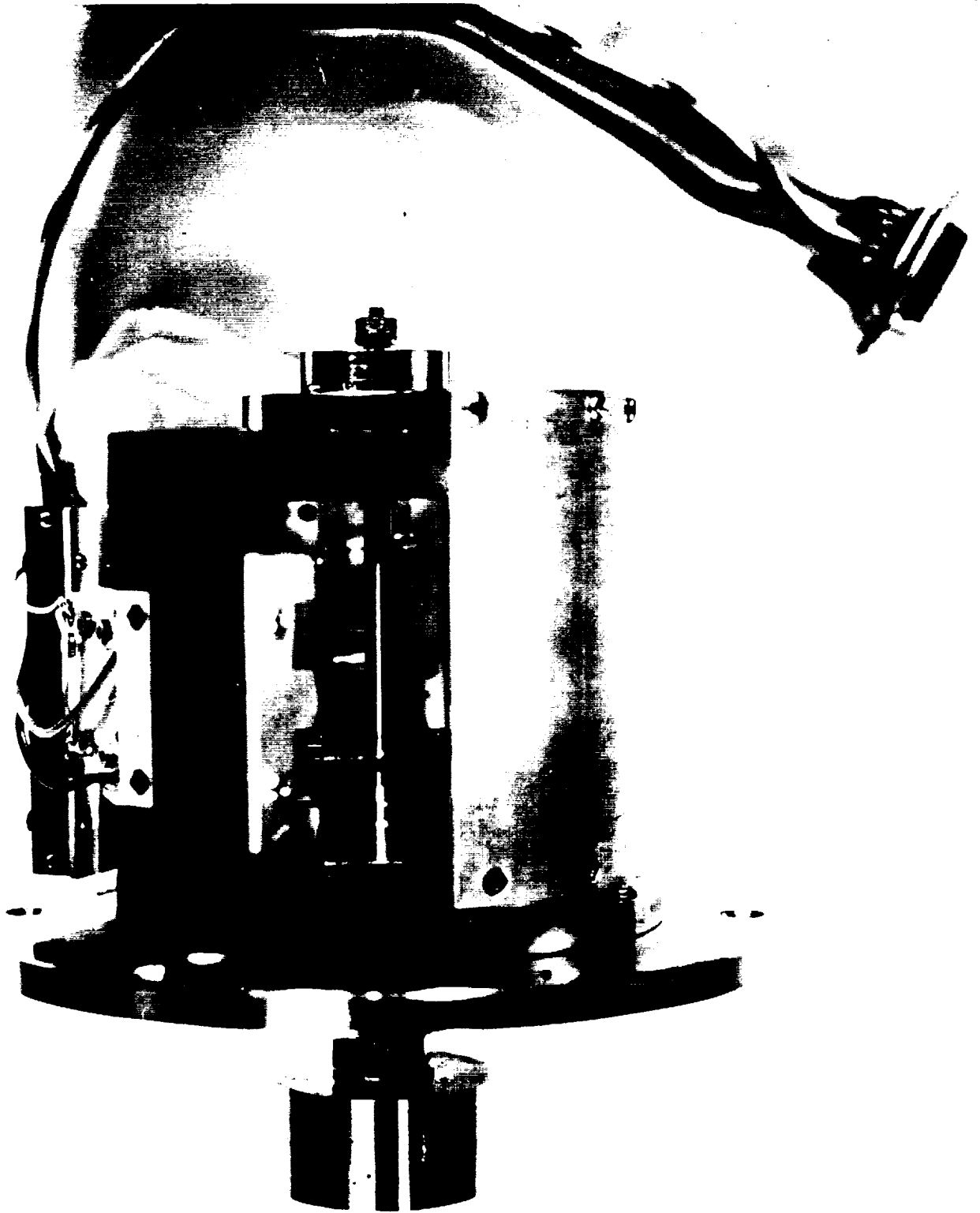


NAS 5-9629 FIG. 4

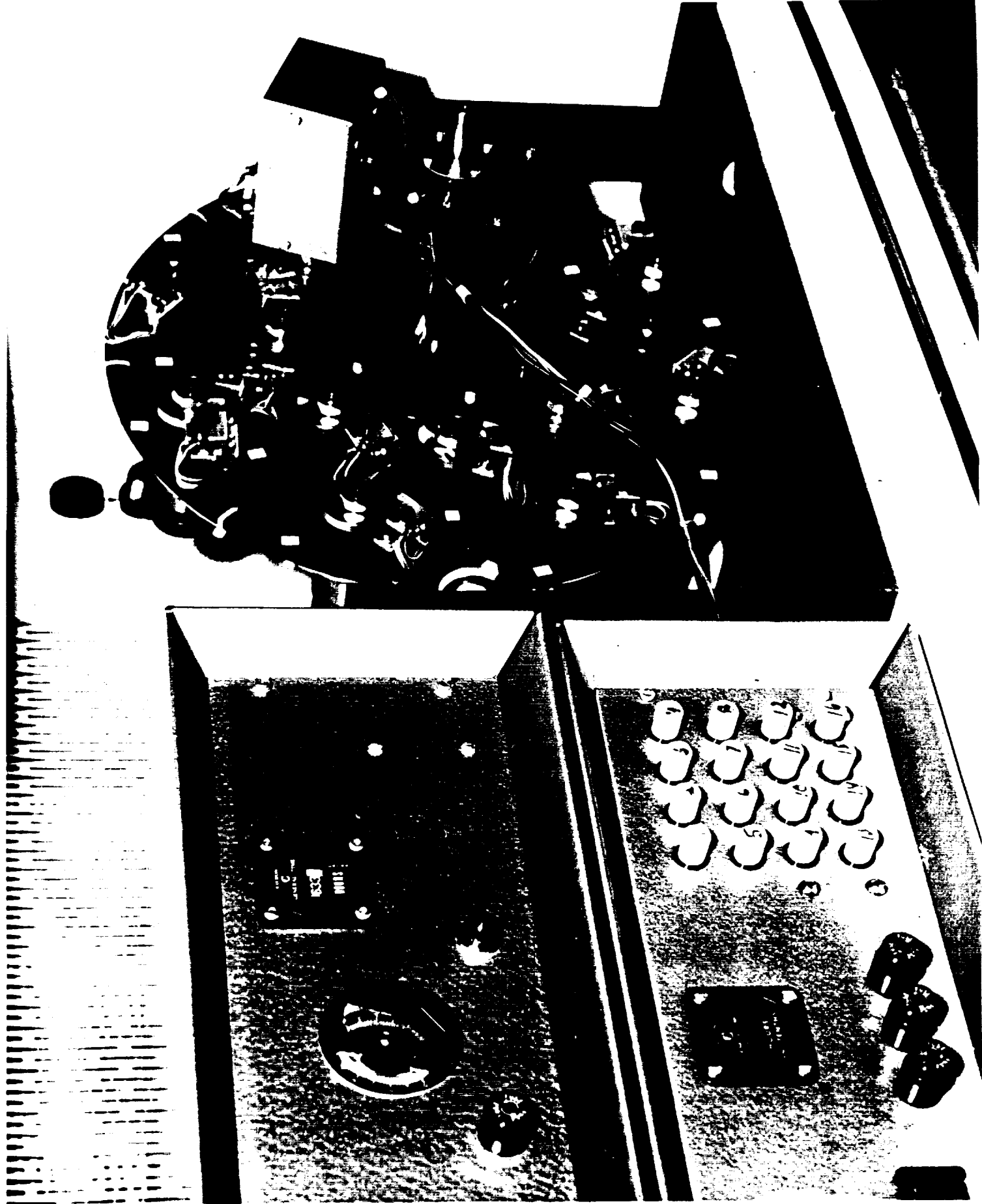
U N I T E D S T A T E S A I R F O R C E S



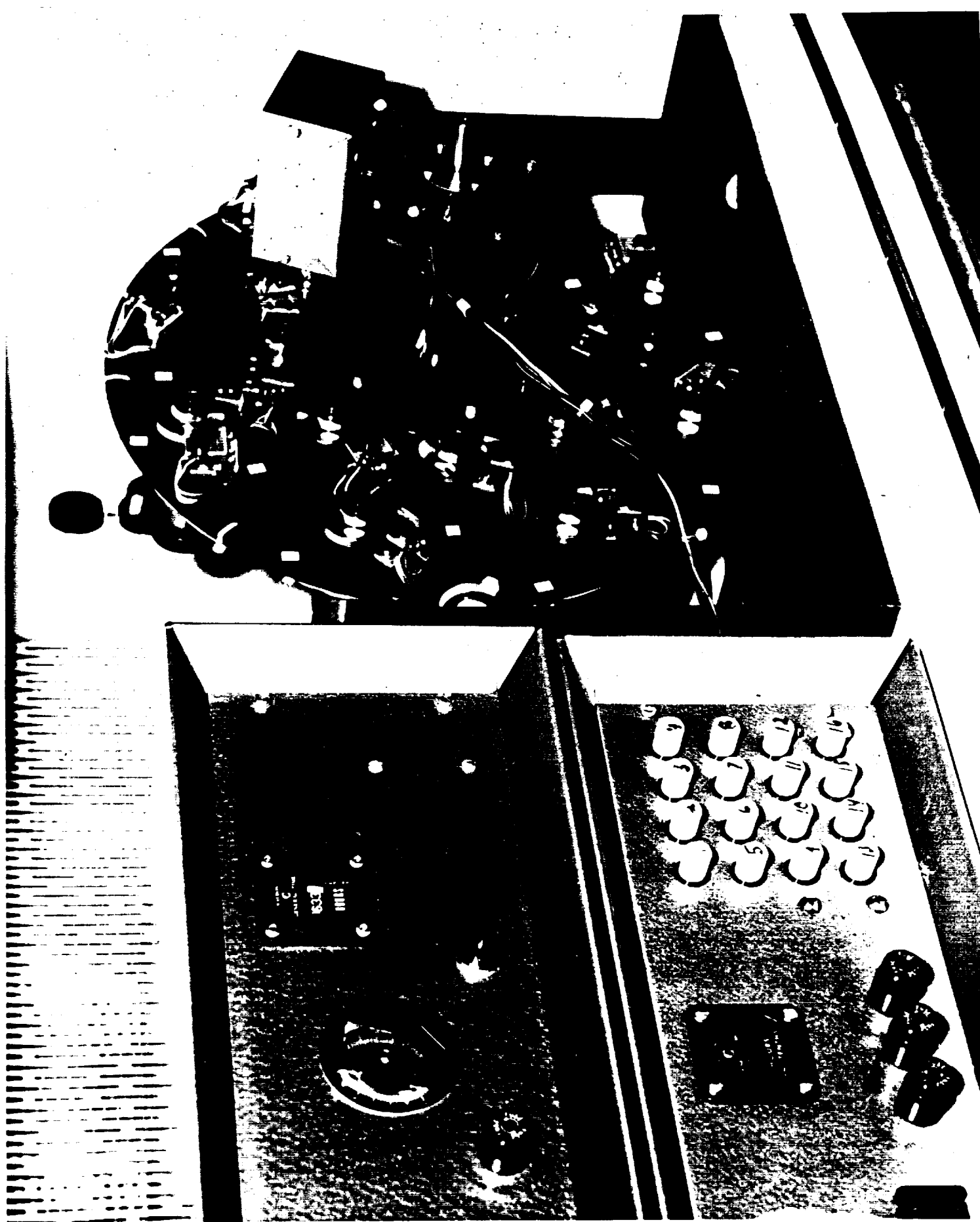
NAS 5-9624 FIG. 4



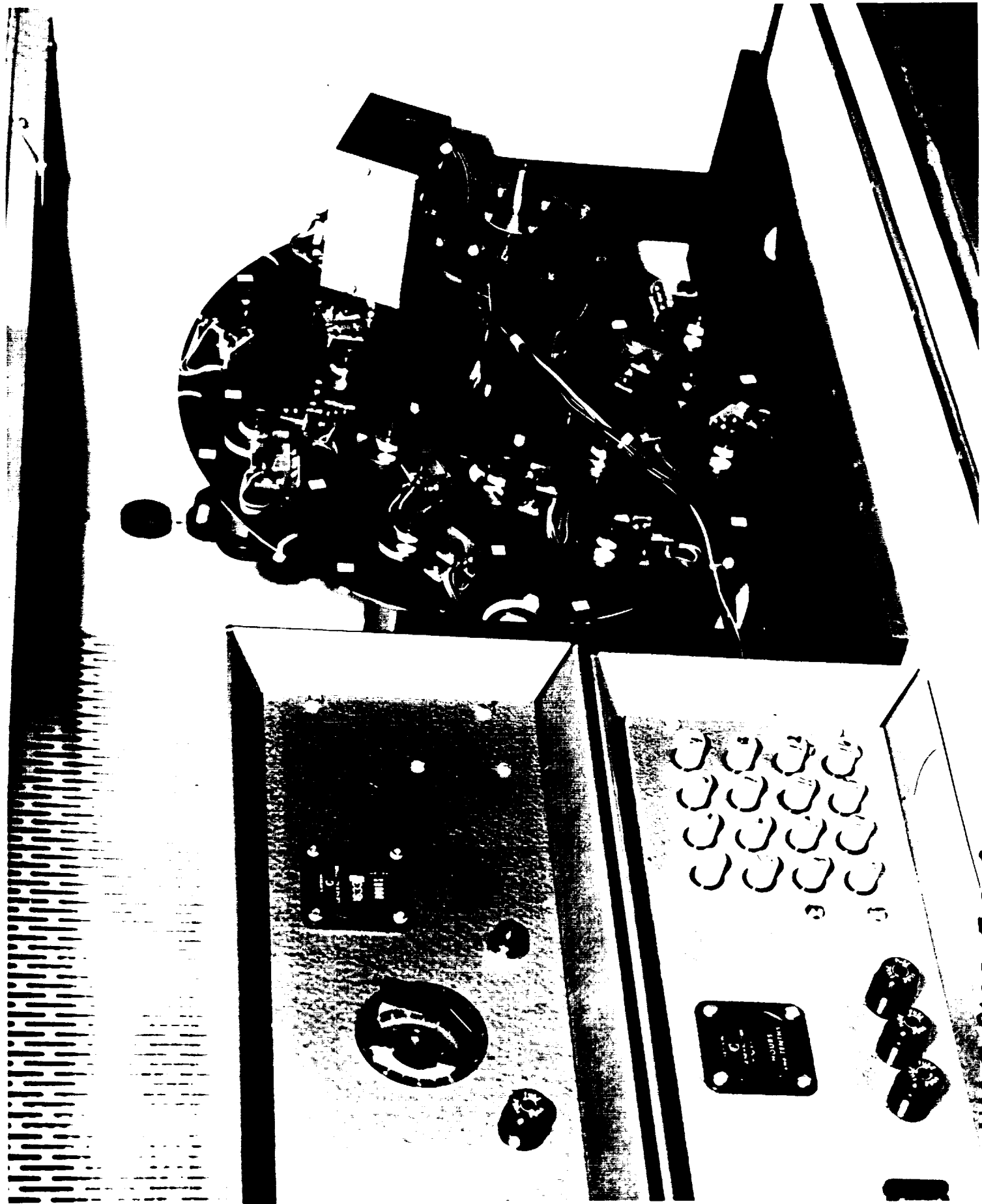
WAS 5:9624 FIG. 2



NAS 5-8138 BIC 5



NAS 5-9622 FIG 5



UAS 5-9628 FIG. 5